Assessing heat stress in hospital wards using Wet Bulb Globe temperature:

A case study in Mediterranean climate

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ABSTRACT: In the context of climate change, there is increasing concern about the likelihood of overheating in hospitals.The aim of this paper is to investigate the heat stress exposure through the Wet Bulb Globe Temperature (WBGT) heat index in four different rooms of the 1st Internal Medicine Department of the American Hellenic Educational Progressive Association (AHEPA) hospital located in Thessaloniki, Greece. In hospital environments patients usually have restricted adaptive opportunity. Thus, the need for an indoor heat-safety metric is imperative. This study proposes thresholds of 24°C and 26°C to assess critical ward spaces as these are the initial warning points for nighttime thermal discomfort of healthy individuals in 'normal' environments. In this context, the internal temperatures measured in the patients' rooms were plotted against the indoor WBGT thresholds for a low wind velocity of 0.1m/sec. Between the 13th and the 22th of June 2017 the most extreme temperatures were recorded in room 3, while the mildest conditions occurred in room 1. WBGT ranged between 19°C and 25.46°C. The recorded WBGT in three rooms exceeded the threshold of 24°C for approximately one-third of the time, while in one room it was marginally below the proposed threshold.
KEYWORDS: Heat stress, Wet bulb globe temperature, monitoring, hospital.

1. INTRODUCTION

Climate projections predict extreme weather around the globe in the coming decades. One of the expected consequences of a changing world climate is that uncharacteristically high external temperatures (often referred to as 'heat waves') have become more intense, longer lasting, and more frequent. Heat is an environmental hazard and its serious impact on human well-being creates a great challenge for public health and associated institutions. According to United Nations projections, urban populations will continue to grow over the next decades. The combined effect of extreme weather events and the increasingly populated urban areas will lead to risk of overheating in buildings. As more and more people spend the majority of their time indoors, this will in turn expose the occupants to heat stress vulnerability within the current building stock. This is likely to become an increasingly important and critical issue, even in the temperate climate of central Europe (50-55°N).

Therefore, there is an increasing concern about the health impacts costs due to elevated indoor temperatures, especially during the night. Moreover, contemporary buildings depend to a large extent on artificial systems to maintain indoor performance to a satisfactory level. This fact renders indoor environment inhabitable without the consumption of energy and other natural resources, since in many cases the provision of passive cooling may be more difficult to achieve. Generally, a building's primary function is to provide optimum thermal conditions (temperature, humidity and air movement) to support occupants with a safe, livable indoor environment. Therefore, it is imperative for buildings to be resilient in a changing climate and provide acceptable conditions particularly during heat waves.

In most cases, people can create comfortable thermal conditions in physiological, behavioral, and cultural terms. Humans can adapt to different climates and environments in innumerable ways. However, the tolerance ranges, regarding temperature of an individual narrows with age. Moreover, people with physical vulnerability are also at high risk of heat-related mortality. Therefore, hospital buildings offer a wide range of heat and health related challenges, as they shelter the most vulnerable individuals (elderly people and people with chronic medical conditions). In addition, hospital buildings provide a wide range of different activities that function 24 hours a day and they store a large amount of essential equipment vulnerable to heat. This fact, render hospitals and healthcare facilities special places, where the resilience to prolonged high temperatures is very critical. Particularly, an increasing concern has developed about the provision of a safe environment, particularly during high extreme temperatures in hospitals which are not mechanically cooled.

2. RESEARCH METHOD

The aim of this paper is to assess the potential Wet Bulb Globe Temperature (WBGT) heat index to evaluate the heat stress exposure in hospital spaces. For this purpose this research project monitored four different rooms of the 1st Internal Medicine Department of the American Hellenic Educational Progressive Association (AHEPA) hospital located in Thessaloniki, Greece.

Firstly, a detailed building survey was carried out to collect data on the structure, age, type, geometry and orientation of the hospital along with information regarding the HVAC systems, the heating controls and the appliances used by the occupants. Additional information was collected through drawings, field measurements, observations and interviews with facility management and other staff.

Secondly, measurements (monitoring) were carried out in the selected patients' rooms. Considering the constraints and limitations to monitor globe temperature and wind speed in a hospital environment, the research project focused on internal temperatures and relative humidity levels so that WBGT could be used effectively to assess heat stress in a meaningful way. Data were collected between the 13th and the 22th of June 2017. The limited period was largely due to resource constraints and access limitations. By and large, the monitored period was a reflection of early summer conditions. During this period, Air conditioning within the patients' rooms was turned off. At the same time, the daytime outside temperature was fluctuating between 25ºC and 33ºC and it was dropping to 18ºC to 24ºC during the night. The selected spaces have different number of beds and a different orientation.

Furthermore, an algorithm was developed to generate the heat stress graphs. The algorithm solves polynomial heat stress equations proposed by Bernard and Pourmoghani (1999) and provides Air Temperature values for the corresponding Relative Humidity values from 0.0 to 100.0 by step 0.1. The algorithm runs on python programming language.

3. HEAT STRESS IN HEALTHCARE FACILITIES

Heat stress is a common problem in many industrial situations, athletic and military activities. Many scientific studies have shown a direct and measurable link between individual performance and the heat conditions in enclosed spaces. Globally, many efforts have been made to indicate the level of the environmental heat stress that is inflicted by a wide range of ambient and work conditions. However, studies focused on indoor heat stress on health related issues for the general population in non-industrial settings is very limited. The most indoor overheating research relies on indoor-outdoor temperature differences and has no common indoor heat index for evaluating indoor heat stress. The need is even more critical in health care facilities considering patient care plans. However, Holmes et al. (2016) are of the opinion that the data from the healthcare facilities and hospital studies conducted during heatwaves in the absence of mechanical cooling begin to suggest certain indoor heat-health thresholds.

Generally, heat stress is highly linked to human thermoregulation. Human body can reach thermal equilibrium by balancing the heat gains and losses while responding to the prevailing environmental factors (air temperature, humidity, air speed and radiant temperature) by adjusting (metabolic rate and clothing) properly to the conditions. The zone of homeothermy includes the zone of thermal comfort which requires minimum heat production; however, it also includes uncomfortable conditions where the body itself does not have the capacity to maintain thermal balance. When the human body is not able to maintain thermal equilibrium, the heat stress of hypothermia or hyperthermia begins. The correlation between homeothermy zone and comfort and heat stress can be seen in Figure 1.

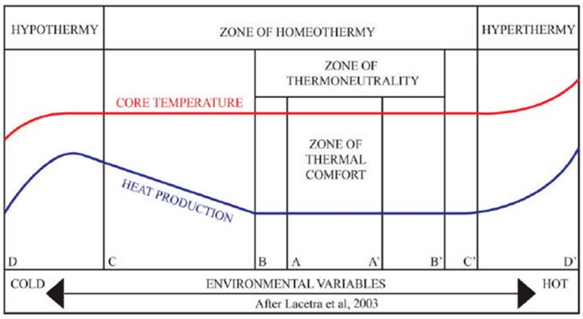

Figure 1: Homeothermy

Heat stress is often associated with the term 'overheating'. On most occasions, this condition is assessed using adaptive thermal comfort standards based on BSEN 15251 and ASHRAE 55. However, an indoor environment considered uncomfortable by these standards may still be safe for occupation provided it is not inducing heat stress on its occupants. This is unlikely to be applicable to patients considering low level of body resilience and care plan. In reality, a patient could experience a heat stress below the overheating threshold of 28°C. It is also important to note that, in hospital environments, patients on most occasions have restricted adaptive opportunities. Their mobility (change clothing level, standoff of an uncomfortable place) and the ability to thermoregulate by acting suitably may be seriously limited.

4. THE WET-BULB GLOBE TEMPERATURE (WBGT) HEAT STRESS INDEX

The assessment of the thermal stress taking into account physiological and psychological strain is a complex issue. There are three groups that can categorize heat stress: “rational indices”, “empirical indices”, or “direct indices”. Rational and empirical indices combine environmental and physiological variables; they are hard to be assessed and are not practical for every day utilize. However, the last category is based on the monitoring of the main environmental factors (air temperature, humidity, and air speed), offering more applicable indices.

The wet-bulb globe temperature (WBGT) has been used globally by many occupational safety agencies for heat stress assessment. More specifically, WBGT (in °C) is an empirical thermal index, developed in the 1950s, that measures natural wet bulb temperature (T_{nwb} in °C) and black globe temperature (Tg in °C) However, it is not easy to measure globe temperature in a hospital ward as there are a lot of functional constraints. Bernard and Pourmoghani (1999) have suggested a simplified equation (Equation 2) and it was validated by Lemke and Kjellstrom (2012) to assess indoor conditions. The equation is based on psychrometric wet bulb temperature (T_{pwp} in °C), dry bulb temperature (Ta in °C) and air speed (V in m/s). Generally, it is assumed that occupants are healthy adults.

$$WBGTind=0.7Tnwb+0.3Tg \quad (1)$$

$$WBGT=0.67Tpwp+0.33Ta-0.048log10V(Ta-T_{pwp}) \quad (2)$$

where T_{pwp} = Tw

$$Tw= Ta\ atan\ (0.151977(RH+8.313659)1/2) + atan\ (Ta+RH)\ atan\ (RH1.676331) +0.00391838(RH)\ 3/2atan\ (0.023101RH) - 4.686035 \quad (3)$$

In equation 2, indoor radiant temperature is considered equal to indoor air temperature; removing radiant temperature from the equation. Indoor operative temperature is what is measured more frequently in a low air speed hospital, which is a combination of air and radiant temperature.

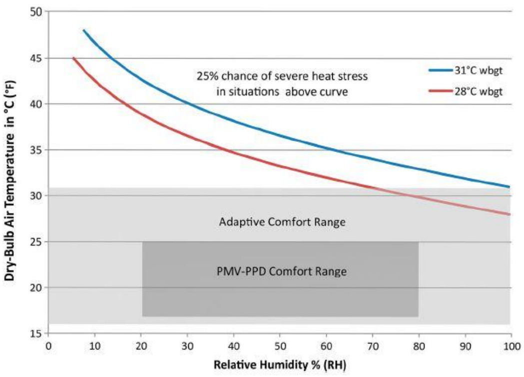

Figure 2: Indoor WBGT (0.3 m/s) and its relationship to BSEN 15251 adaptive threshold

Figure 2 demonstrates the WBGT thresholds of 31°C and 28°C in connection to dry-bulb temperatures and RH levels. The equation has been validated up to an air speed of 3m/sec. According to Holmes et al. (2016), the WBGT threshold of 31°C is not a suitable for vulnerable and sick people. However, a threshold for 28°C could be proposed for below average healthy people, but it has not been valid for healthcare buildings. Giridharan (2017) in his study on the naturally ventilated ward building at St Albans city hospital, argue a WBGT heat index threshold of 23°C. Overall, the paper displays the importance of combining BSEN15251 adaptive thermal comfort standards and WBGT heat stress index for hospital environmental performance analysis and proposes further investigation considering the maximum value of WBGT as heat stress index for patients.

CIBSE Guide A (2006) states that “thermal comfort and quality of sleep begins to decrease if bedroom temperatures rise much above 24°C” and *“bedroom temperatures at night should not exceed 26°C”* unless if ceiling fans are available”. As there is no WBGT valid threshold for sick and vulnerable people, this study proposes thresholds of 24°C and 26°C to assess critical ward spaces. As these are the initial warning points for nighttime thermal discomfort of healthy individuals in ‘normal’ environments, one could argue these are the heat stress thresholds for sick and vulnerable people. Assuming that temperatures above 24°C invoke impaired sleep and temperatures above 26°C provoke heat stress during sleep to healthy individuals, these thresholds could lead to severe health implications for sick people under naturally ventilated hospitals. Furthermore, this value is less than the threshold of below average healthy people.

5. DESCRIPTION OF CASE STUDY

The 1st Internal Medicine Department consists of 18 patient rooms and an administrative area. It belongs to the first floor of a concrete construction with conventional cavity external walls (50 mm polystyrene insulation) and solid internal walls. Plaster (25 mm) has been used as inner and outer leaf to both internal and external walls. The ward is naturally ventilated and every room is heated by cast iron radiators. Almost all the rooms use air conditioning but measurements were done it was turned off. The 1080m^2 floor area consists of a long central corridor to which rooms of 4-6m depth are connected. On the south and north side, multi-bed rooms occupy the wider parts of the building. The windows run as a continuous ribbon on both facades incorporating opaque elements. Solar gains and glare arising from the south easterly exposure are mitigated by external blinds made of plastic. Every room is equipped with one small TV screen and fluorescent light is used for main lighting. Every bed is supplied with a bedside lamp (fluorescent bulb) for private use.

5.1 DATA COLLECTION

One HOBO UX100-003 data logger was installed inside every room and recorded temperature and relative humidity (within 3.5% accuracy) with its integrated sensors. A short time (two days) dynamic calibration was carried out on all loggers. The loggers collected data from Tuesday 13th of June, at 12:00am until Thursday 22th of June, at 12:00am, registering the mean values within a 15-min interval. The sensors were placed near the patient bed in an average height of 1.10m above the floor, which is equal to the patients' bed height or the upper part of a sitting body. All devices were placed in positions protected from direct solar radiation and far from heat sources or drafts. Figure 3 indicates the spaces in which data collected.

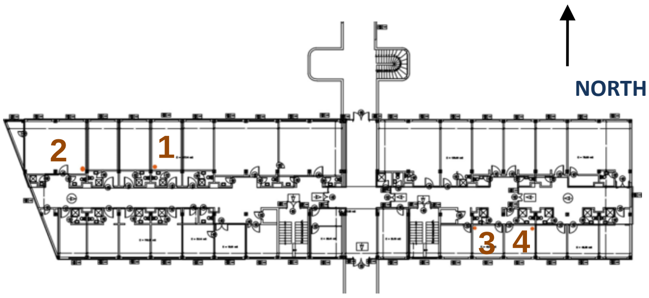

Figure 3: Floor Plan of the 1st Internal Medicine Department, in AHEPA hospital, Thessaloniki. Key: Spaces being monitored: a three-bed room (1) a six-bed room (2) and two bed-rooms (3, 4).

5.2 ASSESMENT OF INDOOR PERORMANCE

The measured data collected by each sensor were complete with no apparent outliers. During the monitoring period, the maximum temperature recorded was 30.7°C, observed in room 3, while a minimum temperature of 25.2°C was recorded in room 2. The maximum observed indoor temperature difference among the rooms was approximately 2°C. The similar pattern between the temperatures is due to the small differences in heat gains of occupancy and equipment, exposed thermal mass of the structural elements-namely concrete ceilings. The mean daytime indoor temperature varied between 27.8°C and 28.6°C, while mean nighttime indoor temperature varied between 27.2°C and 28.5°C.

The maximum WBGT fluctuated between 23.9°C and 25.7°C while the minimum was between 18.9°C and 19.9°C. According to table 1, it can be noted that in most of the rooms the humidity levels were maintained within the recommended comfort standards. Based on international regulations and standards, the recommended levels of indoor relative humidity are 30–60%. Further, it should be noted that at maximum temperature of 29.6°C, the WBGT was less than 24°C. Exposure of the less healthy people to higher temperatures is acceptable as long as it does not cause heat stroke which has a bearing on heat index. There is no research to suggest a heat index threshold for heat stroke in less healthy and sick people. Further heat index has to be different for different category (children, maternity, infections etc.) of sick and less healthy people. However, it appears that for less healthy people, the heat index has to be less than 24. Further research is required to ascertain a more appropriate threshold for less healthy and sick people.

Table 1: Comparison of temperatures measured between 13th June and 22th June in 1st Internal Medicine Department.

Space	Max WBGT(°C)	Min WBGT(°C)	Max Temp (°C)
ROOM 1	23.8	19.5	29.6
ROOM 2	25.4	18.9	30.0
ROOM 3	25.7	19.9	30.4
ROOM 4	25.1	19.1	30.6

Space	Min Temp (°C)	Max RH (%)	Min RH (%)
ROOM 1	26.4	65.5	28.8
ROOM 2	25.2	60.3	35.7
ROOM 3	25.9	60.3	29.5
ROOM 4	25.9	59.6	30.7

In general, higher air velocities are expected to provide more appropriate standards of air quality and temperature. The internal temperatures measured in all of the rooms are plotted against the indoor WBGT thresholds with the lowest air speed of 0.1m/sec, which is considered as the worst case scenario.

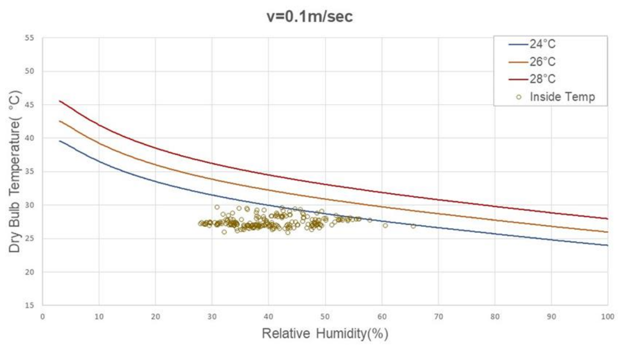

Figure 4: Internal temperatures measured in room 1 are plotted against the indoor WBGT thresholds (0.1m/s)

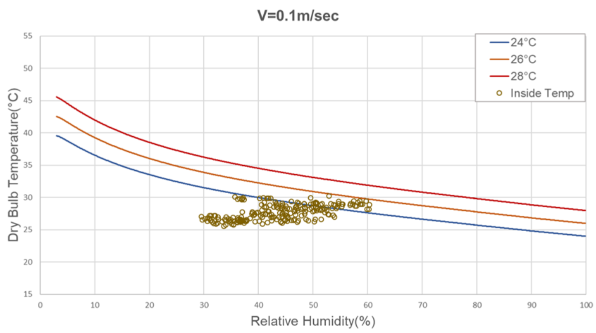

Figure 5: Internal temperatures measured in room 2 are plotted against the indoor WBGT thresholds (0.1m/s)

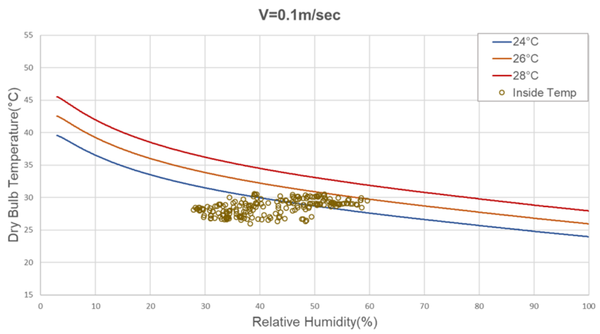

Figure 6: Internal temperatures measured in room 3 are plotted against the indoor WBGT thresholds (0.1m/s)

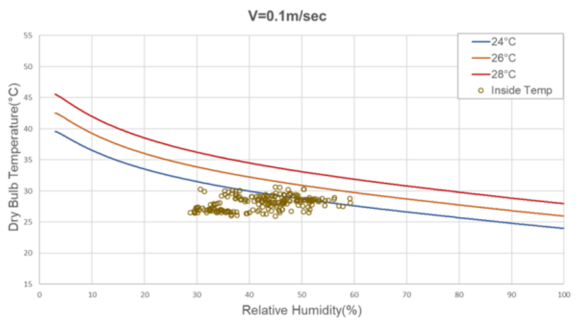

Figure 7: Internal temperatures measured in room 4 are plotted against the indoor WBGT thresholds (0.1m/sec)

As it can be seen from the figures 4 to 6 for the period of 13th to 22th of June 2017, the most extreme temperatures were recorded in room 3, while the mildest conditions occurred in room 1. For a wind velocity of 0.1m/sec which constitutes the worst case scenario, the recorded internal temperatures in room 3 exceeded the threshold of 24°C for approximately one-third of the time, while in room 1 a few temperature values were marginally above the proposed threshold. In rooms 2 and 4 the measured internal temperatures crossed the threshold of 24°C for approximately one-fifth of the time. In none of the rooms the internal temperatures exceeded the limit of 26°C which is the maximum nighttime thermal comfort threshold.

In general, rooms 3 and 4 had the most extreme conditions regarding temperature. The First Internal Medicine Department has south-north orientation. The rooms 1 and 2 are located on the north side and the rooms 3 and 4 have south orientation. In general, northern facing rooms receive the least amount of solar lighting during the year while the rooms facing south receive direct solar light almost all day during year. Moreover, the frequent use of ceiling fans, the use of blinds and open doors, in rooms 1 and 2 may have contributed to higher heat losses to adjacent spaces.

CONCLUSION

This study has reported the thermal performance of four different rooms of the 1st Internal Medicine Department of AHEPA hospital, by applying the WBGT heat index. The most extreme temperatures were recorded in room 3, while room 1 presented the mildest conditions. Consequently, the research highlights the suitability of the rooms with the mildest conditions for those patient groups (e.g. elderly, patients that are easily affected by heat) that are considered the most vulnerable. The study highlights the importance of WBGT heat stress index, especially in hospital environments where the adaptive ability of the patients is limited most of the times. As there is no WBGT valid threshold for sick and vulnerable people, this study proposes WBGT of 24.0°C and 26.0°C as lower and upper thresholds in relation to dry-bulb air temperatures and RH levels for a low air speed of 0.1m/s which is the worst case scenario. These temperature values are the initial warning points for nighttime thermal comfort of healthy individuals in 'normal' environments. Therefore, an argument could be made that these thresholds could lead to severe health implications for sick people under naturally ventilated hospital. The recorded internal temperatures in room 3 exceeded the threshold of 24°C for approximately one-third of the time, while in room 1 a few temperature values were marginally above the proposed threshold. In none of the rooms the internal temperatures exceeded the limit of 26°C which is the maximum nighttime thermal comfort threshold. Finally, the authors believe that less healthy people can adapt to indoor temperatures above 24°C as long as the WBGT heat index is less than 24°C. However to make this concrete a large scale and a long term monitoring is required.

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